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SPECIFICATION

Method of Determining Exercise Intensity and Apparatus Employing the Same

Technical Field

The present invention relates to methods of determining an exercise intensity suitable for each individual, and exercise equipment, exercise intensity determining apparatus and the like allowing users to exercise with a work load thereof.

Background Art

If an bicycle ergometer or any other similar work load apparatus is used to simply measure physical fitness, for example an incremental load (hereinafter referred to as a "ramp load") is applied to the subject, while the subject's heart rate is measured to obtain a relationship between the load and the heart rate to estimate the subject's level of physical fitness. In doing so, a load variation rate needs to be applied to change a ramp load, which herein corresponds to the incremental load, as appropriate, in response to the level of physical fitness of interest.

Conventionally, personal data such as age, sex and weight are entered and referred to to provide a ramp load variation rate matching a standard level of physical fitness for the entered personal data. Such a ramp load variation rate is determined, for example as represented by the flowchart shown in Fig. 65. In the Fig. 65 flowchart, the control initially determines whether the subject is no less than 60 years old (ST 91), then whether the subject is no more than 40 kg in weight (ST 92), and then whether the subject is no less than 80 kg in weight (ST 93). From these decisions the control then determines whether the subject is male or female (ST 94, ST 96, ST 98) and from the decision the control determines a ramp load variation rate to be 5 W/min., 10 W/min., 15 W/min., and 20 W/min. (ST 95, ST 97, ST 99, ST 100).

In addition to such individual information, the presence/absence of physical fitness (i.e., whether the subject has a high, average or low level of

physical fitness) is entered or previously obtained measurements of physical fitness are used to determine ramp load variation rate. If the presence/absence of physical fitness is entered, ramp load variation rates are provided, by way of example, as follows:

	male	female
for average level of physical fitness	15	10
for low level of physical fitness	8	5
for high level of physical fitness	25	15

(unit: W/min.)

Thus, before a subject start exercise, his/her age, sex or other individual information as well as the physical fitness level that the subject thinks he/she belongs to are entered and a ramp load variation rates preset as above is thus applied.

However, if entered personal data is referred to to determine a ramp load variation rate, a subject having a level of physical fitness lower than a standard may receive an excessive load. Furthermore, if a subject has physical fitness greater than a standard, his/her physical fitness level would not be estimated accurately as it is time-consuming to measure physical fitness of such a subject. Furthermore, it is cumbersome to input personal data such as age, sex and weight and some subjects also do not want their personal information known to others while such information is entered.

Furthermore, if in addition to personal information the presence/absence of physical fitness entered is also used to determine a ramp load variation rate, a subject who does not know his/her physical fitness level may enter an inappropriate physical fitness level. Furthermore, if physical fitness measurement is used to determine a ramp load variation rate, the physical fitness measurement must previously be obtained, which is also cumbersome.

There is also disclosed an apparatus used to determine appropriate exercise levels. For example, Japanese Patent National Publication No. 9-509877 discloses a conventional technique referring to a level of heart rate

variability to determine an exercise intensity (an exercise level). This document discloses a method of determining an exercise intensity for a subject from a variation in value of the heart rate of the subject in exercise. This technique utilizes the fact that as an exercise intensity increases a heat rate variation value monotonously decreases, and a heart rate variation value of a subject in exercise is thus referred to to determine an exercise intensity.

Furthermore more than one article also report that a heart rate variability value tends to decrease as an exercise intensity increases or that HI(0-0.15 HZ) and LO(0.15-1.0 HZ) of a power spectrum derived from a heart rate variability also tend to decrease as an exercise intensity increases.

There is also a report that diabetes when they are doing exercise have a heart rate variability significantly smaller in absolute value than those physically fit, as disclosed for example in "Autonomic Nervous Activity at Rest and during Exercise in Diabetes," Toshio Moritani et al, Kyoto University, Graduate School of Human and Environmental Studies.

While the above-described, conventional method can determine an exercise intensity without any particular problem for those physically fit, it cannot determine an exercise intensity for a subject, such as diabetes, having a variability pattern which does not decrease monotonously, as described in the above report. Thus the method can only be applied to a limited range.

Furthermore, the conventional method described above can only determine an exercise intensity from a heart rate variability and in practice there has not been developed a method noting a difference of a variability pattern attributed to a morbidity such as diabetes, and thus referring to a variability pattern during exercise to also detect the fitness level of the subject.

The present invention has been made noting such disadvantages as described above and it contemplates exercise equipment allowing an each individual to have exercise with an appropriate work load, an apparatus capable of accurately estimating the physical fitness level of each individual,

and an apparatus capable of determining an appropriate exercise intensity for each individual.

The present invention also contemplates a method capable of determining exercise intensities for individuals including both those physically fit and patients for example with diabetes, an apparatus aiding in determining a physical condition from exercise, an apparatus for use in measuring a physical condition, and exercise equipment having these functions.

Disclosure of the Invention

The present invention provides exercise equipment including: a work load means providing a variable work load; a physiological signal measurement means noninvasively measuring a physiological signal during an exercise involving the work load means; and a load decision means driven by a physiological signal obtained during the exercise, to determine a load variation rate of an incremental or decremental load, the load decision means changing a work load at the load variation rate.

The present exercise equipment can determine a load variation rate of an incremental or decremental load matching each individual and a work load varies at the determined load variation rate. This can eliminate the necessity of inputting age, sex, weight or any other similar personal information and previously measuring the physical fitness level of the individual, and in addition without the necessity of determining an appropriate physical fitness level each individual can have an exercise with an optimal load and hence without receiving an excessive load or an insufficient load.

The present invention in another aspects provides an apparatus estimating a physical fitness level, including: a physiological signal measurement means noninvasively measuring a physiological signal during an exercise; a load decision means driven by the physiological signal obtained during the exercise, to determine a load variation rate of an incremental or decremental load; and a physical fitness level estimation means estimating a physical fitness level from a relationship between a work load and a heart rate during an exercise with the load incremented or

decremented at the load variation rate determined.

The present physical fitness level estimation apparatus can accurately estimate the physical fitness level of each individual through exercise.

The present invention in still another aspects provides an apparatus determining an exercise intensity, including: a physiological signal measurement means noninvasively measuring a physiological signal during an exercise; a load decision means driven by a physiological signal obtained during the exercise, to determine a load variation rate of an incremental or decremental load; and an exercise intensity decision means determining an optimal exercise intensity from a relationship between a work load and a heart rate variability during an exercise with the load incremented or decremented at the load variation rate determined.

The present invention in still another aspects provides an apparatus determining an exercise intensity, including: a physiological signal measurement means noninvasively measuring a physiological signal during an exercise; a load decision means driven by a physiological signal obtained during the exercise, to determine a load variation rate of an incremental or decremental load; and an exercise intensity decision means determining an optimal exercise intensity from a relationship between a work load and power spectrum of heart rate variability during an exercise with the load incremented or decremented at the load variation rate determined.

The present apparatus determining an exercise intensity can determine an optimal exercise intensity for each individual through exercise.

Preferably the exercise equipment further includes a work load unit providing a variable work load based on one of a physical fitness level obtained from the apparatus estimating a physical fitness level and an exercise intensity obtained from the apparatus determining an exercise intensity.

The present exercise equipment can provide an exercise with an optimal work load for each individual.

The present invention in still another aspects provides a method of

determining an exercise intensity, noninvasively measuring a physiological signal during an exercise having a load, determining a variation pattern of the physiological signal from the physiological signal for an obtained work load variation with a work load being applied, and determining an appropriate exercise intensity with the variation pattern determined taken into consideration.

In the present method while a work load is applied a variation pattern of a physiological signal can be determined and with the determined variation pattern taken into consideration an appropriate exercise intensity can be determined. Thus an appropriate exercise intensity can be determined accurately not only for those physically fit but diabetes, those having high blood pressures and those having similar diseases. Herein the variation pattern is determined in a warmup from a predetermined time interval associated with a work load increasing or from a physiological signal variation rate for each work load value interval.

The present invention in still another aspects provides exercise equipment including a load device providing a variable load, a physiological signal measuring means measuring a physiological signal invasively over time, and an exercise intensity determination means determining from a physiological signal obtained from the physiological signal measuring means for a work load variation a variation pattern of the physiological signal with a work load being applied, and determining an appropriate exercise intensity with the pattern determined taken into account, wherein the load device provides a load set to correspond to the exercise intensity determined by the exercise intensity determination means.

The present exercise equipment allows an individual to have an exercise with an optimal exercise intensity whether the individual is physically fit or has diabetes, high blood pressure or other similar disease.

The present invention in still another aspects provides exercise equipment including a load device providing a variable load, a physiological signal measuring means measuring a physiological signal invasively over time, and a physical condition determination means determining from a physiological signal obtained from the physiological signal measuring

means for a work load variation a variation pattern of the physiological signal with a work load being applied, and determining a physical condition from the pattern determined.

The present exercise equipment can check a physical condition through exercise.

The present invention in still another aspects provides an apparatus providing an assistance to determine a physical condition, including a physiological signal measuring means measuring a physiological signal invasively over time, a variation pattern determination means determining from a physiological signal obtained from the physiological signal measuring means for a work load variation a variation pattern of the physiological signal with the work load being applied, and an output means outputting the pattern determined.

The present apparatus providing an assistance to determine a physical condition can determine and output a variation pattern of a physiological signal that is introduced when a work load is being applied. From the output variation pattern can be determined whether the individual of interest is physically fit or has abnormality in his/her autonomic nervous system that is associated with diabetes, high blood pressure or other similar diseases.

The present invention in still another aspects provides a measurement apparatus including a physiological signal measuring means measuring a physiological signal invasively over time, a physical condition determination means determining from a physiological signal obtained from the physiological signal measuring means for an obtained work load variation a variation pattern of the physiological signal with a work load being applied, and determining a physical condition from the pattern determined, and an output means outputting the physical condition determined.

If the present measurement apparatus is incorporated, e.g., into a bicycle ergometer a user thereof can obtain information on his/her physical condition through exercise.

Brief Description of Drawings

In the drawings:

Fig. 1 is a block diagram showing a circuit configuration of an ergometer according to an embodiment of exercise equipment of the present invention;

Fig. 2 is a perspective view of an appearance of the bicycle ergometer;

Fig. 3 illustrates another exemplary electrocardiosensor used in the bicycle ergometer, attached to a subject doing exercise;

Fig. 4 illustrates still another exemplary electrocardiosensor used in the bicycle ergometer, attached to a subject doing exercise;

Fig. 5 illustrates a pulse sensor used in the bicycle ergometer, attached to a subject doing exercise;

Figs. 6A and 6B are a list of classes in value of variability power used in automatically controlling a ramp load, as represented in the Fig. 7 flow chart;

Fig. 7 is a flow chart of an example of an operation of the bicycle ergometer;

Fig. 8 is a flow chart following the Fig. 7 flow chart;

Fig. 9 illustrates how a work load corresponding to an optimal exercise intensity is determined from a variability power convergence;

Fig. 10 is a flow chart of a process for determining a variability convergence;

Fig. 11, together with Fig. 10, is a flow chart of a process for determining a variability convergence;

Figs. 12A and 12B represent a relationship between ramp load and variability power;

Fig. 13 is a flow chart of a process for automatically controlling a ramp load in the Fig. 7 flow chart;

Figs. 14A-14C show an exemplary indication that an optimal exercise intensity has been determined;

Figs. 15A-15C show an exemplary indication of an exercise intensity;

Figs. 16A-16C illustrate a condition when a training mode is set for an optimal exercise intensity;

Figs. 17A-17C illustrate how a physical fitness level is determined from a relationship between a work load and a heart rate;

Figs. 18A and 18B show an exemplary indication displayed when a physical fitness level has been determined;

Fig. 19 is a flow chart of a process effected in the Fig. 13 flow chart at a step STa;

Fig. 20 is a flow chart of a process effected in the Fig. 13 flow chart at a step STb;

Figs. 21 and 22 are a flow chart of a process effected in the Fig. 13 flow chart at a step STc;

Fig. 23 is a flow chart of a process effected in the Fig. 13 flow chart at a step STd;

Fig. 24 represents data of a 28 year old, male subject having his optimal exercise intensity determined by means of a bicycle ergometer of the embodiment;

Fig. 25 represents data of a 23 year old, female subject having her optimal exercise intensity determined by means of the bicycle ergometer of the embodiment;

Figs. 26A and 26B illustrate variation patterns *a* and *b*, respectively, in heart rate variability power during exercise;

Figs. 27A and 27B illustrate variation patterns *c* and *d*, respectively, in heart rate variability power during exercise;

Fig. 28 is a flow chart of an example of an operation of the bicycle ergometer;

Figs. 29A-29C show an exemplary indication displayed in the bicycle ergometer when an optimal exercise intensity has been determined;

Figs. 30A-30C show an exemplary indication displayed to indicate an exercise intensity after an optimal exercise intensity has been determined:

Fig. 31 illustrates an exemplary exercise program execution with an optimal exercise intensity applied;

Fig. 32 is a flow chart of a pattern decision process of the Fig. 8 flow chart;

Fig. 33 is a flow chart of a process for determining exercise levels *a* and *b* in the Fig. 32 flow chart;

Figs. 34A-34C illustrate how an exercise intensity is determined from a variability power convergence;

Fig. 35 is a flow chart of a process for determining exercise level *c* in the Fig. 32 flow chart;

Fig. 36 illustrates another example of determining an exercise intensity from variability power;

Fig. 37 is a flow chart of a process for determining exercise level *d* in the Fig. 32 flow chart;

Fig. 38 illustrates still another example of determining an exercise intensity from variability power;

Fig. 39 is a flow chart representing another example of the process for determining exercise levels *c* in the Fig. 32 flow chart;

Fig. 40 is a plan view of a displaying portion of a display provided in an operation unit of the bicycle ergometer;

Figs. 41A and 41B are plan views showing a specific example of an indication displayed on the Fig. 40 displaying portion;

Figs. 42A and 42B show an example of an indication displayed to present a variability power variation pattern;

Fig. 43 is a flow chart representing another example of the operation of the bicycle ergometer;

Fig. 44 is a flow chart following the Fig. 43 flow chart;

Fig. 45 represents a variability power variation pattern relative to a work load;

Fig. 46 is a class list used in the Figs. 48-49 flow chart to determine a variation pattern;

Fig. 47 shows the level of each of the Fig. 46 classes *a-e*, as seen in variability power;

Fig. 48 is a flow chart specifically representing an example of a process for determining a variability power variation pattern;

Fig. 49 is a flow chart representing a process 3 of the Fig. 48 flow chart;

Fig. 50 is a flow chart representing a process 4 of the Fig. 48 flow chart;

Fig. 51 is a flow chart following a branch B of the Fig. 48 flow chart;

Fig. 52 is a flow chart following a branch D of the Fig. 41 flow chart;

Fig. 53 is a flow chart following a branch E of the Fig. 41 flow chart;

Fig. 54 is a flow chart following a branch C of the Fig. 48 flow chart;

Fig. 55 is a flow chart representing a process 2 of the Fig. 48 flow chart;

Fig. 56 is a flow chart following a branch G of the Fig. 55 flow chart;

Fig. 57 is a flow chart following a branch F of the Fig. 55 flow chart;

Fig. 58 is a flow chart following a branch I of the Fig. 57 flow chart;

Fig. 59 is a flow chart following a branch H of the Fig. 55 flow chart;

Figs. 60A-63 represent patterns *a-j* of the Figs. 48-59 flow charts;

Fig. 64 is a graph of entropy versus time and Fig. 64B is a graph of work load versus time; and

Fig. 65 is a flow chart of an example of conventionally determining a ramp load variation rate from age, sex, weight and other similar personal information entered.

Best Mode for Carrying out the Invention

First Embodiment

Fig. 1 is a block diagram showing a circuit configuration of a bicycle ergometer according to an embodiment of exercise equipment of the present invention. This ergometer includes a electrocardiosensor 1 detecting an electrocardiographical signal, a preamplifier 2 amplifying a signal output from electrocardiosensor 1, a noise removing filter 3, an amplifier 4 further amplifying an electrocardiographical signal to an appropriate level, an A/D converter 5, a CPU 6 executing a variety of processes, a key entry unit 7, a display 8 indicating an exercise intensity, a physical fitness level and the like, and a load device 9 capable of providing a variable, rotative load. CPU 6 has various functions. For example it determines a load variation rate of an incremental or decremental load from a physiological signal obtained during exercise (a "load decision function"). It also applies the determined load variation rate of the incremental or decremental load and also refers to

a relationship between a work load and a heart rate during exercise to estimate a physical fitness level (a "physical fitness level evaluation function"), or it applies the determined load variation rate of the incremental or decremental load and also refers to a relationship between a work load and a heart rate variability during exercise with the incremental or decremental load imposed or a relationship between a work load and a power spectrum of heart rate variability during exercise with the incremental or decremental load imposed, to determine an optimal exercise intensity (an "exercise intensity decision function").

Fig. 2 is a perspective view of an appearance of the bicycle ergometer. As shown in Fig. 2, the ergometer includes a saddle 11, a handle 12, an operation unit 13 having key entry unit 7, display 8, an announciator (not shown) and the like, a pedal 14, a front foot 15, and a rear foot 16. Handle 12 has a pair of electrodes 17 (a physiological signal measurement unit) for electrocardiographic detection. When a subject holds electrodes 17 with both hands his/her hands contact electrodes 17 and from the hands a electrocardiographical signal is detected.

A subject sits on the ergometer at saddle 11 and works and thus rotates pedal 14 to do exercise. Pedal 14 receives a work load to have a weight corresponding to a degree of exercise intensity and for a large work load, rotating pedal 14 certain times of course requires a large amount of exercise, which is well known.

Note while the Fig. 2 embodiment provides electrodes 17 for electrocardiographic detection arranged at handle 12, it is capable of variation. For example, as shown in Fig. 3, a chest belt 14 having a pair of electrodes and a transmitter is attached to a subject M around the chest and handle 12 has a receiver 42, which corresponds to the Fig. 2 operation unit 13. A electrocardiographical signal is detected from the chest of subject M and transmitted to receiver 42 by wireless and then processed.

Fig. 4 shows an example of chest lead type, with three, positive (+), negative (-) and ground (G) electrodes 45, 46, 47 attached to subject M at the chest and also connected to circuitry of the main body via a cable 48 to detect an electrocardiographical signal.

In the example shown in Fig. 5, the sensor is replaced by a pulse sensor 49 attached to subject M at a lobe to detect a pulse.

The exercise equipment thus configured determines a load variation rate of an incremental or decremental load from a physiological signal obtained during exercise, such as an electrocardiographical waveform (an electrocardiographical signal) detected by an electrocardiosensor, a pulse wave signal (a pulsation signal) detected by a pulse sensor, or any other similar physiological signals provided in response to an variation in work load. The load variation rate of the incremental or decremental load is determined by a method, as will now be described, by way of example. In the method, an incremental load (hereinafter referred to as a "ramp load") is determined with a physiological signal corresponding to a heart rate and a level of heart rate variability power.

Initially, during exercise a heart rate and a level of heart rate variability power are detected. The heart rate is calculated, as follows: During exercise, a electrocardiographical signal is detected via electrode 17 provided in the ergometer at handle 12. The signal's peak is then detected and therefrom a RR interval data (one period of the heart rate) is calculated. For example, five heart beats of the interval are averaged to calculate a heart rate. Furthermore, variability power (Power) is determined from the following equation (1):

$$\mathrm{Power}(n)\ [\mathrm{ms}^2] = \{\mathrm{RR}(n) - \mathrm{RR}(n-1)\}^2 \qquad (1)$$

This is a square of a difference between the current one period and the previous one period and it is herein referred to as heart rate variability power. In data Power, for example an average for 30 minutes is calculated at 15-second intervals.

For the heart rate and variability power thus calculated, the automatic ramp load control point values shown in Fig. 6 are for example used to determine a ramp load variation rate. Herein points *a*-*e* and points subsequent thereto are provided. More specifically, point *a* serves as a value Wup in a warmup and it is an average for the latter one minute of a

warmup of two minutes. Subsequently, point *b* is the value when two minutes have elapsed since the end of the warmup (P2min), point *c* is the value when three minutes have elapsed since the end of the warmup (P3min), point *d* is the value when four minutes have elapsed since the end of the warmup (P4min), point *e* is the value when five minutes have elapsed since the end of the warmup (P5min), and after six minutes have elapsed since the end of the warmup a value for each one minute is similarly used. These points *a-e* correspond to positions, as shown in Fig. 6B, when they are seen on a variation curve indicating a tendency of typical variability power toward an exponential reduction during an exercise using ergometer applying a ramp load.

In the above exercise equipment (the ergometer) a ramp load is automatically controlled to determine an optimal exercise intensity, as represented exemplarily in the flow chart shown in Figs. 7 and 8. Note that an optimal exercise intensity herein is for example a variability power convergence during an exercise with a load applied and it is a work load obtained when such a convergence appears.

In Fig. 7 when a user press a key of the Fig. 1 key entry unit 7 to take an measurement a measuring process starts. Initially at step (ST) 1 electrocardiosensor 1 detects an electrocardiographical signal. Electrocardiosensor 1 outputs a signal, which is calibrated to have a predetermined level (ST2). More specifically it is calibrated by adjusting a gain in amplifier 4 in response to a signal output from CPU 6. After the calibration completes, display 8 indicates "measurement starts" (ST3) and the control starts controlling load device 9 (ST4). In doing so, for example an initial load value 15 [w] is applied for a 2-minute warmup and a ramp load of 10 [W/min] is then first applied.

Then an electrocardiographical signal has a peak value thereof detected and, as has been described previously, a heart rate and variability power are calculated (ST5, ST6). Note that in doing so the average heart rate and variability power in the warmup have also been calculated. For example, in a 2-minute warmup, as a heart rate is calculated an average for 15 minutes after a temporal period of one minute and a half has elapsed (an

HR of Wup) and as variability power, value Wup (see Fig. 6A) is calculated. This heart rate and variability power calculation continues until two minutes have elapsed since the warmup started (ST7). When the two minutes have elapsed the control determines whether it is a timing at which a ramp load should be controlled (ST8) and if so then from a heart rate and variability power measured the control sets a ramp load variation rate, as appropriate, accommodating the physical fitness level of each individual (ST9).

A ramp load is automatically controlled, as shown in Fig. 13. More specifically, a warmup starts and thereafter when three minutes elapse the control proceeds with the STa process (ST81), when four minute elapses it proceeds with the STb process (ST82), when five minutes elapse it proceeds with the STc process (ST83), and when six minutes or more elapse it proceeds with the STd process (ST84). Each process will be described hereinafter.

Following the Fig. 7 ST 7 the control determines whether a convergence appears (ST10).

The control determines that a convergence has appeared and thus determines an optimal exercise intensity if variability power variation characteristics satisfy the following conditions (a) and (b):

(a) variability power has a value below a predetermined power base line; and

(b) the difference from the previous variability power [Power{T(n – 1)} – Power{T(n)}, i.e., the gradient of the variability power variation curve does not exceed a defined gradient.

Note that an optimal exercise intensity may indicate the heart rate or work load for the convergence point shown in the Fig. 24.

An optimal exercise intensity is determined for example as shown in Fig. 9. In Fig. 9, from a variability convergence a work load at an intersection of time-work load characteristics is obtained as an optimal exercise intensity. This convergence point is determined, as will now be described with reference to the flow chart shown in Figs. 10 and 11. This flow chart represents a process for determining a convergence that is used in

determining an exercise intensity for a typical pattern. Steps ST61-ST 65 are similar to the Fig. 8 steps ST1-ST5. More specifically when a user presses a key of key entry unit 7 to take a measurement a measurement process starts. Initially, electrocardiosensor 1 detects an electrocardiographical signal (ST61), and electrocardiosensor 1 outputs a signal, which is calibrated to have a predetermined level (ST62). More specifically it is calibrated by adjusting a gain in amplifier 4 in response to a signal output from CPU 6. After the calibration completes, display 8 indicates "measurement starts" (ST63) and the control starts controlling load device 9 (ST64). In doing so, for example an initial load value 20 [w] is applied for a 2-minute warmup and a ramp load of 15 [w] is then applied per minute.

Then an electrocardiographical signal has a peak value thereof detected and equation (1) is used to calculate variability power (ST65). After the calculation, the control determines whether the two minutes of the warmup have elapsed (ST66) and if not then the control returns to ST65. When following the end of the warmup a temporal period of two minutes has elapsed, ST67 has a decision YES and a power baseline of 25 [ms^2] and a gradient of 6 [ms^2] are set (ST70, ST71).

Then a convergence point is determined (ST68). With reference to Fig. 12 representing variability power variation characteristics (a variation in variability power and work load with time), as the work load increases the variability power decreases and converges. The variability power in a variability curve converges at a point AT. Herein a convergence point corresponding to point AT is determined when variability power has a value below a predetermined reference value and it has a difference from the previous power value [Power{T(n – 1)} – Power{T(n)}, i.e., the gradient of the variability power variation curve] that drops below a predetermined power baseline. More specifically, if the control cannot determine a convergence point then it makes a decision NO and increments a work load (ST69) and repeats ST66-ST68. If the control determines a convergence point then the exercise intensity corresponding to the calculated load value is indicated on display as a result (ST72). Note that in the flow chart the variability power

used for pattern classification is as shown in Fig. 6A and classes a-e in variability power correspond to the positions as shown in Fig. 6B.

If in the Fig. 8 at ST10 the control cannot determine a convergence point or an optimal exercise intensity, the control makes a decision NO and it increments a load according to the set ramp load (ST11), returns to ST5 and continues to calculate a heart rate and variability power to determine a convergence point.

When an optimal exercise intensity is determined, the load value applied one minute before the optimal exercise intensity has been determined is calculated and a work load corresponding to the optimal exercise intensity calculated is indicated on display 8 (ST12). For example, it may be displayed, as shown in Figs. 14A through 14C, horizontally scrolled to indicate "optimal exer-","-cise intensity" and "determined" and thereafter the exercise intensity may be indicated, as shown in Figs. 15A through 15C. Herein a point indicating a "level 5" of a plurality of load levels is a best mode (Fig. 15A) and as other examples of displaying it a "heart rate (beats/min)" (Fig. 15B), a "work load (W)" (Fig. 15C), and the like are indicated. After the result is displayed the work load is decreased and the subject thus has a cooldown for a predetermined period of time (for example of one minute) (ST13). The control completes controlling the work load (ST14).

Note that while in the Fig. 7 and 8 flow chart, determining an optimal exercise intensity is followed by having the subject have a cooldown and then terminating the exercise, a training program may be provided, rather than terminating the exercise, to reduce the load to approximately half the determined optimal exercise intensity to have the subject have an exercise with this light load for approximately one minute and then again increase the light load to the optimal exercise intensity and thus enter a training mode with the optimal exercise intensity.

The training program entering a training mode with an optimal exercise intensity is executed for example as shown in Figs. 16A-16C. More specifically, an optimal exercise intensity is initially determined (Fig. 16A at *a*) and the work load is then reduced to approximately half the optimal

exercise intensity (Fig. 16A at *b*) and with the reduced work load the subject has an exercise approximately for one minute and the work load is then again increased to the determined optimal exercise intensity (Fig. 16A at *c*) to execute an exercise program controlled with the optimal exercise intensity.

Furthermore, a physical fitness level can also be determined by automatically controlling a ramp load, as described above, to determine the physical fitness level from a relationship between a heart rate and a load value obtained when the subject has an exercise with the ramp load. It can be determined as will now be described more specifically by way of example with reference to Figs. 17A-18B. Initially, a relationship between a heart rate obtained during an exercise with a ramp load applied, as controlled automatically, as described above (for example from the end of an warmup until 75% of HRmax is attained), and a work load (Fig. 17B), is used to calculate an expected maximal work load (Wmax [w]) corresponding to an expected maximal heart rate (HRmax [bpm]) (Fig. 17C). For the exemplified 75% of HRmax, the age of the subject is entered via key entry unit 7 and Hlmax equals 220 minus the age is internally calculated. From the time and gradient during a ramp load exercise with a heart rate corresponding to 75% of the calculated value, Wmax [w] is obtained. More specifically, as shown in Fig. 17C, from a relationship between a work load and a heart rate obtained after a warmup ends, a linear approximation line *i* is obtained and a work load (Wmax [w]) for HRmax is estimated. The Wmax calculated is used in a known expression to estimate a maximal oxygen intake (litters/min.), which is in turn divided by the subject's weight to obtain an maximal oxygen intake (ml/Kg/min.) per kilogram for the subject's weight. An evaluation table of maximal oxygen intake based on age and sex is used to determine from the estimated maximal oxygen intake the subject's physical fitness level, e.g., physical fitness levels 1 (inferior) to 6 (extremely superior). A physical fitness level thus determined is indicated, such as shown in Figs. 18A and 18B.

In Fig. 7 at the step of automatically controlling a ramp load (ST9) a ramp load variation rate is for example determined as will now be described

more specifically with reference to the flow charts shown in Figs. 19-23. In the flow charts, each parameter has a reference character, as shown in Fig. 6A. Furthermore, herein, a linear elevation of a heart rate during an exercise by means of the ergometer imposing a ramp load, and an exponential reduction in heart rate variability power, are used as a standard pattern.

In Fig. 19 process STa is effected when a temporal period of three minutes has elapsed since a warmup started, as shown in the Fig. 13 flowchart. (Note that in Figs. 19-23, STa, STb, STc, STd, ... correspond to ST1, ST2, ST3, ST4 ..., respectively, in a sense that one minute, two minutes, three minutes,..., respectively, have elapsed since a warmup started, although herein STa, STb, STc, STd, ...are used to distinguish them from The Fig. 7 ST1, ST2, ST3, ...) A heart rate when one minute has elapsed since the warmup started, HR of Wup, is obtained. HR of STa is compared with HR of Wup, a heart rate obtained in the Fig. 7 flow chart at ST5 (ST15) and if the heart rate has a significant elevation then the load variation rate is reduced. For example if a heart rate has an elevation [ΔHR1{(HR of STa) minus (HR of Wup)}] greater than 15 [bpm] then the current ramp load variation rate is decreased by 5 [W/min.] to be 5 [W/min.] (ST16). If ΔHR1 is no more than 15 [bpm] then the load variation rate of 10 [W/min.] is maintained.

With reference to Fig. 20, process STb is effected when a temporal period of four minutes has elapsed since a warmup started. A heart rate (HR of STb) and variability power (P2min) are obtained when a temporal period of two minutes has elapsed since the warmup started (ST21). HR of STb is compared with HR of Wup (ST22) and if the heart rate has a significant elevation then the load variation rate is reduced. If the heart rate does not have a significant elevation and the variability power has a reduction rate smaller than for Wup then the load variation rate is increased. For example if a heart rate has an elevation [ΔHR2{(HR of STb) minus (HR of Wup)}] greater than 20 [bpm] then the current ramp load variation rate is decreased by 5 [W/min.] to be 5 [W/min.] (ST24). Note however that if the current ramp load variation rate is no more than 5 [W/min.] (ST23) the

current load variation rate is maintained.

If ΔHR2 is less than 5 [bpm] (ST25) and variability power is greater than two thirds of the power for Wup (ST26) then the control determines that variability power has a small reduction rate and the control increases the current load variation rate by 5 [W/min.] and if the current load variation rate is 5 [W/min.] then it is increased to 10 [W/min.] and if it is 10[W/min.] then it is increased to 15 [W/min.] (ST27). If at both of ST22 and ST 25 the control makes a decision NO, the current load variation rate is maintained.

With reference to Figs. 21 and 22, process STc is effected when a temporal period of five minutes has elapsed since the warmup started. A heart rate (HR of STc) and variability power (P3min) are obtained when a temporal period of three minutes has elapsed since the warmup ended (ST31). HR of STb is compared with HR of STb obtained one minute before (ST32) and if the heart rate has a significant elevation then the load variation rate is reduced. If the heart rate does not have a significant elevation and the variability power has a reduction rate smaller than for Wup then the load variation rate is increased. For example if a heart rate has an elevation [ΔHR3{(HR of STc) minus (HR of STb)}] greater than 15 [bpm] then the current ramp load variation rate is decreased by 5 [W/min.]. For example if the current load variation rate is 15 [W/min.] then it is decreased to 10 [W/min.] and if it is 10[W/min.] then it is decreased to 5 [W/min.] (ST34). Note however that if the current ramp load variation rate is less than 10 [W/min.] (ST33) the current load variation rate is maintained.

If variability power has as large an absolute value as no less than 500 [ms^2] (ST35) or ΔHR3 is less than 5 [bpm] (ST38) and variability power is greater than one half of the power for Wup (ST39) then the control determines that variability power does not have a large reduction rate and for the both the control increases the current load variation rate by 5 [W/min.] and if the current load variation rate is 5 [W/min.] then it is increased to 10 [W/min.] and if it is 10[W/min.] then it is increased to 15 [W/min.] (ST37, ST41). Note that if in the former and latter cases the

current load variation rate is no less than 15 [W/min.] (ST36, ST40) the current load variation rate is maintained. Furthermore if the control makes a decision NO at any of STs 32, 35, 38, the current load variation rate is maintained.

With reference to Fig. 23, process STd is effected when a temporal period of six minutes has elapsed since the warmup started. For example a heart rate (HRR of ST4) and variability power (P4min) are obtained when a temporal period of four minutes has elapsed since the warmup ended (ST51). Note that in the figure, for ST"*" a value represented by minute is applied according to the time having elapsed since a warmup ended. In the present example, a temporal period of four minutes has elapsed since the warmup ended and ST"d" [d = 4] is thus provided. For the same reason, in the figure, for P"*"min, * = 4. If variability power has as large an absolute value as no less than 500 [ms^2] (ST52) then the control determines that variability power has a small reduction rate and the control increases the current load variation rate by 5 [W/min.] and if the current load variation rate is 5 [W/min.] then it is increased to 10 [W/min.] and if it is 10[W/min.] then it is increased to 15 [W/min.] (ST55). Note that if the current load variation rate is no less than 20 [W/min.] (ST54) the current load variation rate is maintained.

When HR of STd is compared with HR of STc obtained one minute before (ST53) and if the heart rate has a significant elevation (NO) then the load variation rate is maintained. For example if a heart rate has an elevation [ΔHR4{(HR of STd) minus (HR of STc)}] greater than 5 [bpm] then the current ramp load variation rate is maintained. If at ST 53 the control makes a decision YES and variability power has an absolute value greater than a preset power baseline Pbase (ST56) then the current load variation rate is increased by 5 [W/min.] and if the current load variation rate is 5 [W/min.] then it is increased to 10 [W/min.] and if it is 10[W/min.] then it is increased to 15 [W/min.] (ST58). Note however that if the current ramp load variation rate is no less than 20 [W/min.] (ST57) the current load variation rate is maintained. If at ST 52, ST 53 the control makes a decision NO the current load variation rate is maintained.

Thus after the temporal period of four minutes has elapsed following the end of the warmup a heart rate and heart rate variability power are similarly calculated every minute. For the heart rate is considered an elevation in value from a value obtained one minute before and the heart rate variability power is determined from its magnitude in absolute value, and from the obtained results a ramp load variation rate is changed. Note however that a ramp load has a lower limit of 5 [W/min.] and an upper limit of 20 [W/min.] so that it is not set smaller than 5 [W/min.] or larger than 20 [W/min.].

Thus an accurate physical fitness level and an optimal exercise intensity can be determined for each individual and an appropriate ramp load can be provided to correspond to the physical fitness of each individual. Furthermore, it is not necessary to input personal information such as age, sex and weight before the subject starts exercise. Thus the cumbersome operation to input such information can be eliminated and the exercise equipment can thus be used more conveniently.

An exercise equipment (an ergometer) as described above that automatically controls a ramp load is in effect used to determine an optimal exercise intensity, which is represented in data, as shown in Figs. 24 and 25. Fig. 24 represents data of 28 year old male subject having a high level of physical fitness. For him, after a warmup ends a ramp load variation rate of 10 [W/min.] is first fixed. Thereafter it is changed to 15 [W/min.] and further thereafter to 20 [W/min.]. Furthermore, variability power has a convergence point determined at 8.75 min.

Fig. 25 represents data of a 23 year old female subject having an average level of physical fitness. After a warmup ends a ramp load variation rate of 10 [W/min.] is first fixed and maintained, unchanged. Variability power has a convergence point determined at 6.75 min. In Figs. 24 and 25, there is also provided an auxiliary dotted line extending vertically from the point of the fluctuation power convergence point, and the intersection of the auxiliary line and the heart rate (bpm) curve or line graph indicates a value of an maximal exercise intensity as represented by heart rate and the intersection of the auxiliary line and the work load [w]

curve or line graph indicates a value of an optimal exercise intensity as represented by work load.

Note that while in the flow chart referred to in the above embodiment a physiological signal corresponds to a heart rate and heart rate variability power, it may alternatively be a pulse rate obtained from a pulsation signal. Furthermore, heart rate variability power may be replaced by entropy of heart rate variability. Alternatively, a physiological signal may be power spectrum of heart rate variability. Furthermore while in the above flow chart an incremental load is obtained, a decremental load is also basically similarly obtained.

Second Embodiment

A second embodiment of the present invention will now be described.

The second embodiment provides an bicycle ergometer having an appearance, circuit configuration, electrocardiographical signal detection process and the like similar to those of the bicycle ergometer of the first embodiment.

In the second embodiment, an electrocardiosensor, a pulse sensor and the like detect a physiological signal relative to a work load variation and from the physiological signal its variation pattern with a work load applied is determined and from the determined variation pattern an appropriate exercise intensity is determined and the determined exercise intensity is referred to to control the ergometer to change the intensity to be applied to work pedal 14.

A physiological signal has its variation pattern determined, as will now be described more specifically. Herein a physiological signal corresponds to variability power, as has been described in the first embodiment. This Power data has an average value for 30 minutes calculated at 15-minute intervals, as described in the first embodiment to obtain variability power variation characteristics relative to elevation of work load. The variability power variation characteristics are represented in Figs. 26A and 26B and 27A and 27B. Fig. 26A represents a pattern *a* typical to those physically fit. From the figure it can be seen that for those physically fit a load intensity is exceeded, variability power decreases

exponentially.

Figs. 26B and 27A and 27B represent an example showing that during an exercise a heart rate variability power variation pattern is different from pattern *a* typically observed among those physically fit. The Fig. 26B pattern (a pattern *b*) corresponds to variability power relatively smaller in absolute value than pattern *a*. While pattern b is observed among diabetes and obese people it is also observed among those physically fit. The Fig. 27A pattern (a pattern *c*) corresponds to variability power significantly smaller in absolute value than pattern *a* and hardly varying while exercise intensity increases. Pattern *c* is observed among diabetes and it is also often observed among obese people. In the Fig. 27B pattern (a pattern *d*) variability power significantly decreases at an exercise intensity and it is different from pattern *a* corresponding to variability power exponentially decreasing as exercise intensity increases. Pattern *d* is observed among those having high blood pressure.

Thus, a variability power variation pattern significantly varies between those physically fit and those not. Conventionally, for example a weight reduction program provides exercise intensity set uniformly to be approximately 65% of an expected maximal heart rate. There is a report, however, that it is desirable that diabetes, those having high blood pressure and the like have exercise starting with an exercise intensity lighter than applied to those physically fit. Thus it is preferable that the above variation pattern classification be applied to set for pattern *a* typically observed among those physically fit an exercise intensity corresponding to 65% of an expected maximal heart rate and for pattern *c* observed among diabetes an exercise intensity corresponding to a value slightly smaller than 65% of the expected maximal heart rate.

By providing the above variation pattern classification, for patterns *a* and *b* typically observed among those physically fit an exercise intensity is determined by the above-described method, while for pattern *c*, having a convergence for those physically fit when an exercise starts or in a warmup, a lightest exercise intensity, e.g. that for warmup is determined. For pattern *d*, corresponding to variability power significantly decreasing for an

exercise intensity, an exercise intensity immediately before variability power significantly decreases is for example determined as an exercise intensity to be applied.

An exercise intensity is determined through a process, as will now be by way of example described specifically with reference to the flow chart shown in Figs. 28-33. More specifically, the Figs. 28-33 flow chart represents an example process in which variability power is calculated and a variation pattern is then determined and from the determined pattern an exercise intensity is determined.

In Fig. 28, when a user presses a key of the Fig. 1 key entry unit 7 to start a measurement, as described in the first embodiment, the measurement starts and a process similar to the Fig. 7 process described in the first embodiment starts. Initially at step ST101 electrocardiosensor 1 detects an electrocardiographical signal. Electrocardiosensor 1 outputs a signal, which is calibrated to have a predetermined level (ST102). More specifically it is calibrated by adjusting a gain in amplifier 4 in response to a signal output from CPU 6. After the calibration completes, display 8 indicates "measurement starts" (ST103) and the control starts controlling a work load of load device 9 (ST104). In doing so, for example an initial load value of 20 (w) is applied for a 2-minute warmup and a ramp load of 15 [W/min] is then applied per minute.

Then an electrocardiographical signal has a peak value thereof detected and variability power is calculated from equation (1) (ST105). From the calculated variability power a pattern is determined (ST106).

The pattern is determined, as provided in the flow chart shown in Fig. 32. More specifically in a warmup a magnitude of variability power in absolute value and a variability power reduction rate as a work load increases are used to determine pattern *a*, *b*, *c* or *d*. If a pattern cannot be determined or a variability power convergence point cannot be determined then at ST107 the control makes a decision NO and increments a work load (ST108) and repeats ST105-ST107.

If a pattern has been determined then therefrom an exercise intensity is determined. More specifically, for pattern *a* or *b* exercise

intensity *a* or b is determined, for pattern *c* exercise intensity *c* is determined and for pattern *d* exercise intensity *d* is determined. When at ST107 an exercise intensity has been determined the decision is displayed on display 8 (ST109). It is displayed for example in the forms of a heart rate [bpm], a work load [W], an intensity for the work load, and the like that correspond to an exercise intensity corresponding to the pattern of interest. It is displayed, for example as shown in Figs. 29A-28C, with a screen scrolled horizontally to indicate "optimal exer-", "-cise intensity" and "determined". Then, as shown in Fig. 30A, an exercise intensity is indicated in the form of a heart rate to notify the subject of the current optimal exercise intensity. Note that rather than an exercise intensity in the form of a heart rate, as shown in Fig. 30A, a work load [w] or a level corresponding to a work load of an exercise intensity that is selected from a plurality of levels may be indicated, as shown in Figs 30B and 30C. After the result is displayed, the work load is decreased to allow the subject to have a cooldown for a predetermined period of time (e.g. of one minute) (ST110) and the work load is then stopped (ST111).

The determined exercise intensity is exactly stored in CPU 6 at a storage region and when the load device is subsequently used to provide an exercise the determined exercise intensity stored can be applied to the exercise.

After an exercise intensity is determined the determined exercise intensity is applied to successively execute an exercise program.

A specific example of the program is provided, as described in the first embodiment with reference to Figs. 16A-16C. As shown in Fig. 31A, after an optimal exercise intensity has been determined a work load is once decreased to approximately one half of the optimal exercise intensity (Fig. 31 at *b*) and with the work load applied the subject has an exercise for approximately one minute and the work load is then increased again to the determined optimal exercise intensity (Fig. 31 at *c*) to execute an exercise program controlled by the optimal exercise intensity.

While herein the example is provided for pattern d, for the other patterns a-c an exercise program can also be executed similarly with an

exercise intensity determined to be optimal to the subject of interest. As has been described previously, a determined exercise intensity is indicated on display 8 and the subject is allowed to have a cooldown. Alternatively, indicating a determined exercise intensity on display 8 may be directly followed by controlling a work load to be the determined work load to allow the subject to have an exercise accordingly, rather than allowing the subject to have a cooldown. Furthermore, the determined exercise intensity can be referred to to execute a variety of programs such as weight reduction programs, physical fitness enhancement programs, programs eliminating lack of exercise, and the like. A determined exercise intensity is an optimal exercise intensity matching each individual's physical condition, autonomic nervous system condition and the like observed when it is determined. Thus the subject can have an exercise with an appropriate exercise intensity.

Exercise intensities *a* and *b* in the Fig. 32 flow chart (ST125) are determined, as shown in Fig. 33. Initially, the control determines whether a variability power convergence point can be determined (ST131) and if not then the control returns and if so then a work load corresponding to a variability power convergence point is set as an exercise intensity (ST132). It is determined, as shown in Fig. 34C, by determining a convergence point and referring to a work load corresponding to the convergence point (Fig. 34A) and determining the work load as an exercise intensity for the subject of interest. Exercise intensity *c* (ST26) is set to be an exercise intensity applied in a warmup (herein, the exercise intensity of 20 [w]), as shown in Fig. 35 (ST 133). More specifically, with reference to Fig. 36, for pattern *c* an exercise intensity being applied to a subject finishing a warmup is adopted as an exercise intensity for the subject. Exercise intensity *d* (ST127) is determined as shown in Fig. 37. Initially, the control determines whether a variability power convergence point can be determined (ST134) and if not then the control returns and if so then, as shown in Fig. 38, an exercise intensity applied immediately before variability power significantly drops is adopted as an exercise intensity to be applied (ST135).

For pattern *c*, an exercise intensity of 20[W] is determined since in the above exemplified flow chart a constant work load (of 20 [W]) is applied for warmup. However, if depending on personal information such as age a value setting a work load in a warmup is changed and therewith the subject has an exercise, a value setting exercise intensity c may be determined to be divided accordingly.

One such example is shown in the Fig. 39 flow chart. Initially the control determines whether an subject's age entered via key entry unit 7 is no less than 60 years old (ST136) and if not then the control determines whether the subject's weight is no more than 40 kg (ST137) and if not then the control further determines whether it is no more than 80 kg (ST138) and if not then the control selects 20 [w] as an exercise intensity to be applied (ST140).

If the subject is no less than 60 years old and no more than 40 kg in weight then the control selects an exercise intensity of 15 [w] (ST141). If at ST 38 the control determines that the subject's weight is no more than 80 kg then the control determines whether the subject is male or female (ST139) and if the subject is male then the control selects an exercise intensity of 20 [w] an if the subject is female then the control selects an exercise intensity of 15 [w].

A result obtained in the Fig. 28 flow chart at ST 9 is displayed on display 8 at a displaying portion, such as shown in Fig. 40. This displaying portion is formed by an LCD and has an upper portion including a program displaying mark area 50, a data displaying area 51, a unit displaying area and a program displaying mark area 53 and a lower portion including a graphical representation area 54.

The displaying portion specifically displays an indication, as shown exemplarily in Figs. 41A an 41B. In Fig. 41A, pattern *a* is selected and exercise intensity or level 5 is set. In Fig. 41B, pattern *b* is selected and exercise intensity or level 2 is set. They both have the lower, graphical representation area 54 displaying an exercise intensity and a variability power pattern, scrolled horizontally in the leftward direction.

In the above embodiment, a physiological signal's variation pattern

with a work load applied can be determined and therefrom an appropriate exercise intensity can be determined, wherein the physiological signal may be an electrocardiographical signal or a pulsation signal or else a power spectrum of heart rate variability variation value. Similarly, a heart rate variability pattern can also be determined to determine the subject's physical condition. More specifically, by determining which one of the above-described patterns *a-d* a variability power variation pattern corresponds to, it can be determined whether the subject is physically fit or tends to have diabetic, high blood pressure or the like. As such if a variability pattern is output and displayed, as shown in Figs. 42A and 42B, the subject can obtain information on his/her physical condition. Furthermore, heart rate internal variability power may be replaced by heart rate variability entropy.

A subject's physical condition can be determined through a process, as shown exemplarily in the Figs. 43 and 44 flow chart. In the flow chart is determined a convergence point for use in determining an exercise level for a typical pattern. ST51-ST55 are similar to the Fig. 28 ST1-ST5. More specifically, when a user presses a key of key entry unit 7 to take a measurement a measurement process starts. Initially, electrocardiosensor 1 detects an electrocardiographical signal (ST151), and electrocardiosensor 1 outputs a signal, which is calibrated to have a predetermined level (ST152). More specifically it is calibrated by adjusting a gain in amplifier 4 in response to a signal output from CPU 6. After the calibration completes, display 8 indicates "measurement starts" (ST153) and the control starts controlling a work load of load device 9 (ST154). In doing so, for example an initial load value of 20 (w) is applied for a 2-minute warmup and a ramp load of 15 (w) is then applied per minute.

Then a electrocardiographical signal has a peak value thereof detected and equation (1) is used to calculate variability power (ST155). After the calculation, the control determines whether the two minutes of the warmup have elapsed (ST156) and if not then the control returns to ST155. When following the end of the warmup a temporal period of two minutes has elapsed, ST157 has a decision YES and a power baseline of 25 [ms^2] and a

gradient of 6 [ms^2] are set (ST60, ST61).

Then a convergence point is determined (ST158). With reference to Fig. 45 representing variability power variation characteristics (a variation in variability power and work load with time), as the work load increases the variability power decreases and converges. The variability power in a variability curve converges at a point AT. Herein a convergence point corresponding to point AT is determined when variability power has a value below a predetermined reference value and it has a difference from the previous power [Power{T(n – 1)} – Power{T(n)}, i.e., the gradient of the variability power variation curve] that drops below a predetermined power baseline. More specifically, if the control cannot determine a convergence point then it makes a decision NO and increments a work load (ST159) and repeats ST155-ST158. If the control can determine a convergence point then the exercise intensity corresponding to the calculated load value is indicated on display 8 as a result (ST162). After the result is displayed the work load is decreased and the subject thus has a cooldown for a predetermined period of time (for example of one minute) (ST163). Thus the control completes controlling the work load (ST164).

A variability power variation pattern is determined through a process, as shown exemplarily in the Figs. 48-59 flow chart. Herein, an average of variability power during a warmup, power when two minutes have elapsed since the end of the warmup, that when three minutes have elapsed since the end of the warmup, that when four minutes have elapsed since the end of the warmup, and that when five minutes have elapsed since the end of the warmup, are used to determine the pattern. Note that in the flow chart, the variability power values used in the pattern classification are as shown in Fig. 46 and classes *a-e* in variability power correspond to the positions shown in Fig. 47. In the flow chart, patterns are denoted by reference characters, as shown in Fig. 26, and patterns a-j are shown in Figs. 60A-63, respectively